Evidence for Deposition of Black Carbon in the Springtime Arctic

J.R. Spackman[1,2], R.-S. Gao[1], W.D. Neff[1], J.P. Schwarz[1,2], L.A. Watts[1,2], D.W. Fahey[1,2], J.S. Holloway[1,2], T.B. Ryerson[1], J. Peischl[1,2], O.R. Cooper[1,2], C.A. Brock[1]

[1] NOAA Earth System Research Laboratory, Boulder, Colorado

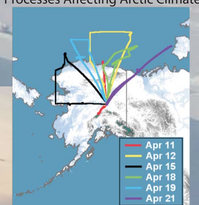
[2] Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado

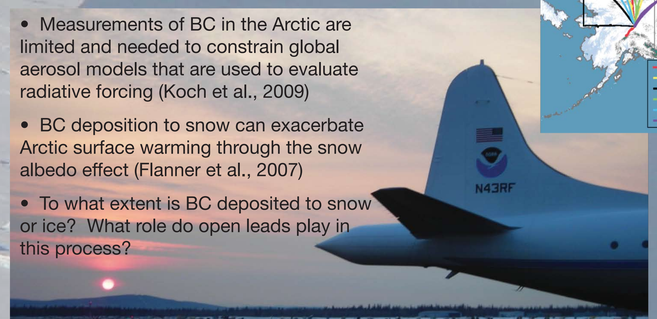
Introduction

Vertical profiles of black carbon (BC) mass were observed from the surface to near 7-km altitude in April 2008 during flights on the NOAA WP-3D research aircraft from Fairbanks, Alaska using a Single-Particle Soot Photometer (SP2). In the free troposphere, the Arctic air mass was often influenced by long-range transport from biomass-burning and anthropogenic source regions at lower latitudes with BC mass loadings reaching maximum values near 4-km altitude. In the boundary layer (BL) over the snow and ice north of Alaska, the air mass was largely decoupled from the advected pollution aloft. In this shallow layer, BC mass loadings decreased from the top of the BL to near the surface by up to a factor of five. The BC gradients in the BL were well correlated with ozone depletion events in all the observations, suggesting that BC particles were removed by dry deposition on the snow or ice in these cases because the short-lived ozone destruction precursor, Br_2, is likely emitted from the sea-ice. Open leads in the sea-ice may facilitate the removal of BC through surface contact by enhancing mixing in the BL. We estimate the deposition flux of BC mass to the snow using a box model constrained by the vertical profiles of BC in the Arctic BL. Understanding the removal of BC in the Arctic BL is crucial for evaluating the impact of anthropogenic and natural sources of BC on Arctic climate.

Motivation

ARCPAC: Aerosol, Radiation and Cloud Processes Affecting Arctic Climate





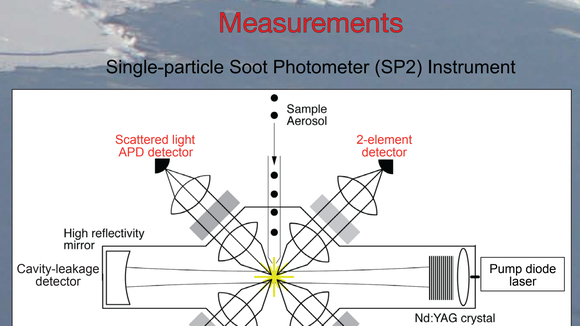
- Measurements of BC in the Arctic are limited and needed to constrain global aerosol models that are used to evaluate radiative forcing (Koch et al., 2009)
- BC deposition to snow can exacerbate Arctic surface warming through the snow albedo effect (Flanner et al., 2007)
- To what extent is BC deposited to snow or ice? What role do open leads play in this process?

Flanner, M. G., C. S. Zender, J. T. Randerson, and P. J. Rasch (2007), Present-day climate forcing and response from black carbon in snow, *J. Geophys. Res., 112*, D11202, doi:10.1029/2006JD008003.

Koch et al. (2009), Evaluation of black carbon estimations in global aerosol models, *Atmos. Chem. Phys., 9*, 9001-9026.

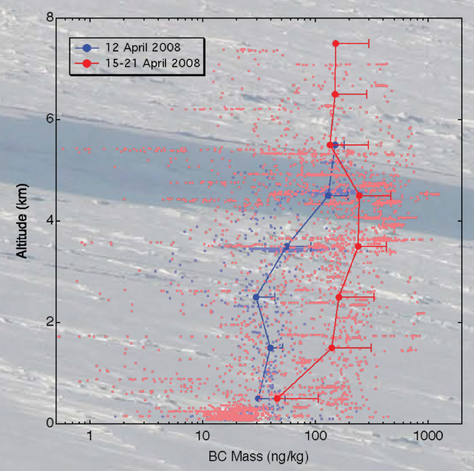
Measurements

Single-particle Soot Photometer (SP2) Instrument



- Single particle soot photometer (SP2) detects refractory black carbon and scattering aerosol
- Laser-induced incandescence is linearly proportional to mass and independent of mixing state of BC particle
- SP2 samples ~90% of BC mass and ~50% of BC number
- Observations: 65-75° N, 0-7.5 km

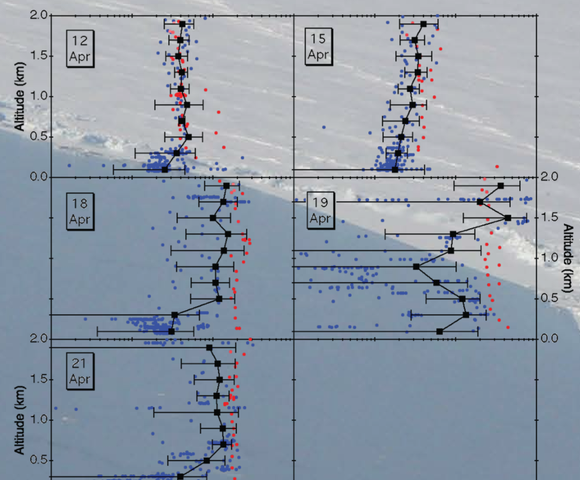
Black Carbon Vertical Profiles in the Springtime Arctic

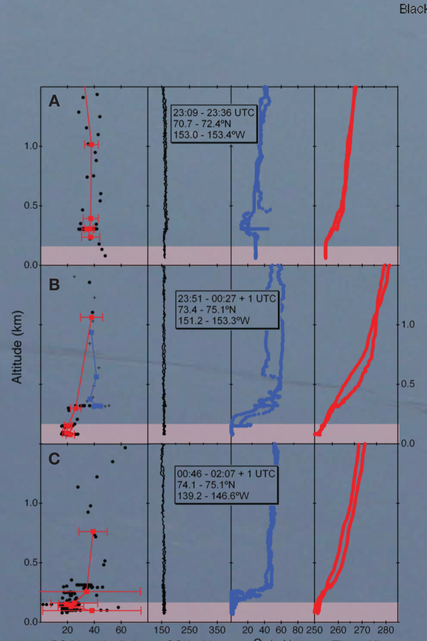


- 12 April 2008: Aged Arctic air mass with lower BC mass loadings
- 15-21 April 2008 (4 flights): Long-range biomass burning emissions with higher BC loadings
- Lower BC mass loadings were observed in the Arctic boundary layer compared to the free troposphere

Black Carbon Depletion in the Arctic Boundary Layer

- Red points: ascent/descent data from Fairbanks influenced by local pollution in the boundary layer
- Blue points: profiles into the boundary layer generally over the ice and polynyas
- Large positive dBC/dZ in the lowest 500 m over the snow and ice

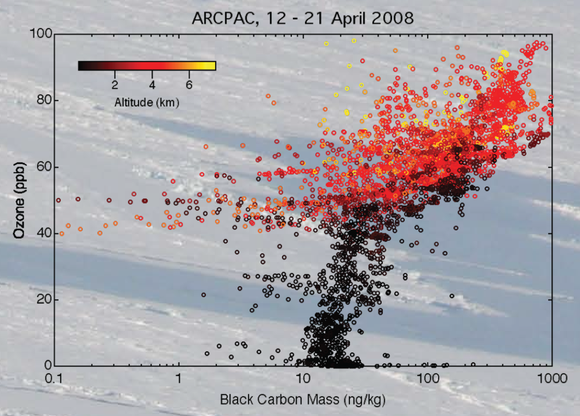




12 April 2008
3 Profile Segments
0 - 1.5 km, > 70°N

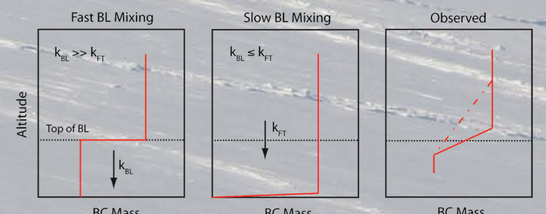
- In **B** and **C**, positive BC gradient with altitude in lower troposphere
- In **A**, limited BC data in BL
- No influence from plumes: CO background values (~160 ppb) extend from the free troposphere into the the BL
- Boundary layer is ~250 m deep over sea-ice
- Profiles are near open leads in sea-ice
- O_3 depletion events are observed simultaneously with BC depletion

Evidence for Black Carbon Deposition

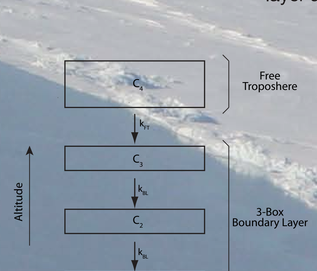


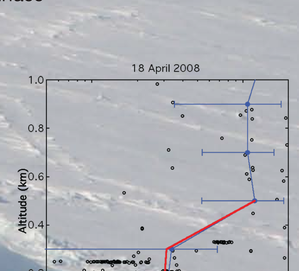
- Compact positive correlation between O_3 and BC in ozone depletion events in the boundary layer
- More processed air contains less BC
- This compact correlation between processed air and BC suggests BC has been removed by surface processing because the very short-lived O_3 destruction precursor, Br_2, is emitted from the snow

Timescales for Deposition



- BL mixing delivers BC to the snow/ice surface where removal occurs faster than BC can be imported from the free troposphere
- BC is mixed from the free troposphere into the BL as fast or faster than BL mixing delivers BC to the surface
- Complete removal of BC occurs in a shallow layer at the surface
- Largest BC gradient often observed at the top of BL
- BC gradient begins as high as 0.5-1 km above the top of the BL





- Relevant timescales:
  (i) Mixing between free troposphere and BL (k_{FT})
  (ii) BL mixing (k_{BL})
- Assume: kBL ~ 8 hour
- Solve system of coupled linear differential equations with constraints:
  (i) Observed BC mass loading at top of BL
  (ii) Shape of profile constrains k_{FT}
- 10-day e-folding time for exchange between the free troposphere and BL
- Dry deposition flux: ~25 ng/(m²-hr)

Conclusions

- BC decreases by a factor of 2 to 5 in vertical profiles from 500 m to 100 m over the ice for many profiles during ARCPAC and is partially attributed to removal
- Dry deposition is likely the dominant removal mechanism because O_3 and BC are positively correlated in ozone depletion events
- Calculated BC dry deposition flux is ~25 ng/(m²-hr) assuming a boundary layer turnover time of 8 hour
- Open leads may enhance (i) mixing in the Arctic BL facilitating the removal of BC on the snow or ice and (ii) entrainment of air from the free troposphere which is often polluted in the springtime Arctic due to long-range transport

Background photo courtesy Dan Lack